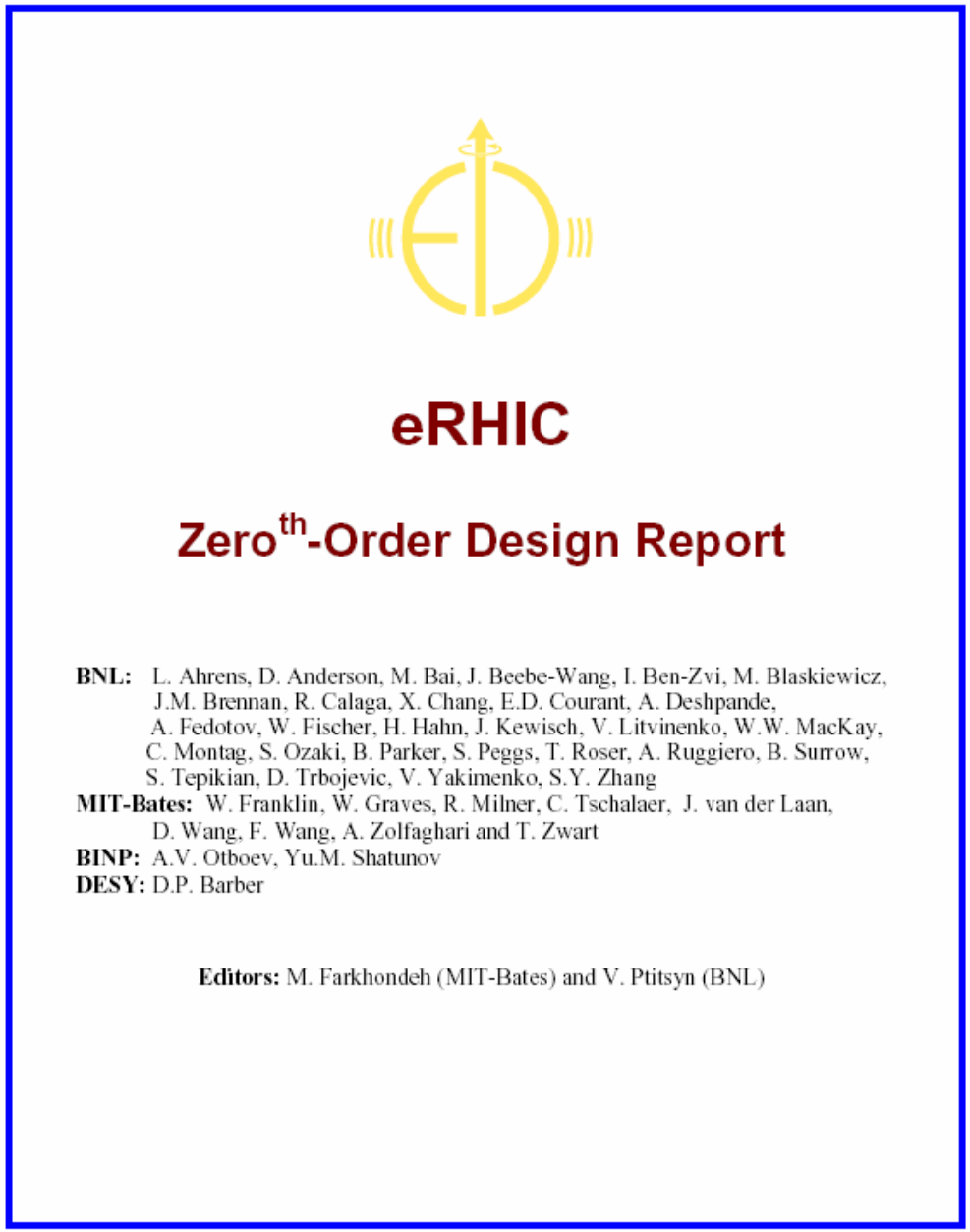
eRHIC General Design and Luminosities

V.Ptitsyn



eRHIC

Zeroth-Order Design Report

BNL: L. Ahrens, D. Anderson, M. Bai, J. Beebe-Wang, I. Ben-Zvi, M. Blaskiewicz, J.M. Brennan, R. Calaga, X. Chang, E.D. Courant, A. Deshpande, A. Fedotov, W. Fischer, H. Hahn, J. Kewisch, V. Litvinenko, W.W. MacKay, C. Montag, S. Ozaki, B. Parker, S. Peggs, T. Roser, A. Ruggiero, B. Surrow, S. Tepikian, D. Trbojevic, V. Yakimenko, S.Y. Zhang

MIT-Bates: W. Franklin, W. Graves, R. Milner, C. Tschalaer, J. van der Laan, D. Wang, F. Wang, A. Zolfaghari and T. Zwart

BINP: A.V. Otboev, Yu.M. Shatunov

DESY: D.P. Barber

Editors: M. Farkhondeh (MIT-Bates) and V. Ptitsyn (BNL)

- Detailed document (265 pages) reporting studies on the accelerator and the interaction region of this future collider.
- The work performed jointly by BNL and MIT-Bates, with close collaboration with scientists from BINP (Novosibirsk) and DESY (Hamburg).
- Goals:
  - to develop an initial design for eRHIC
  - to investigate most important accelerator physics issues
  - to evaluate the luminosities that could be achieved in such a collider

The report web links:

1) www.agsrhichome.bnl.gov/AP/ap_notes/ap_note_142.pdf
2) www.agsrhichome.bnl.gov/eRHIC/eRHIC_ZDR.htm

eRHIC scope

- Experiments with electron-proton and electron-ion collisions.
- Should be able to provide the beams in following energy ranges:
  - 5-10 GeV polarized electrons; (polarized positrons if possible)
  - 50-250 GeV polarized protons; 100 GeV/u gold ions
  - other ion species, especially polarized ^{3}He ions are under consideration.
- Luminosities:
  - in 10^{32} - 10^{34} $cm^{-2}s^{-1}$ range for e-p
  - in 10^{30} - 10^{32} $cm^{-2}s^{-1}$ range for e-Au collisions
- 70% polarization degree for both lepton and proton beams
  - Longitudinal polarization in the collision point for both lepton and proton beams

eRHIC design options and operation modes

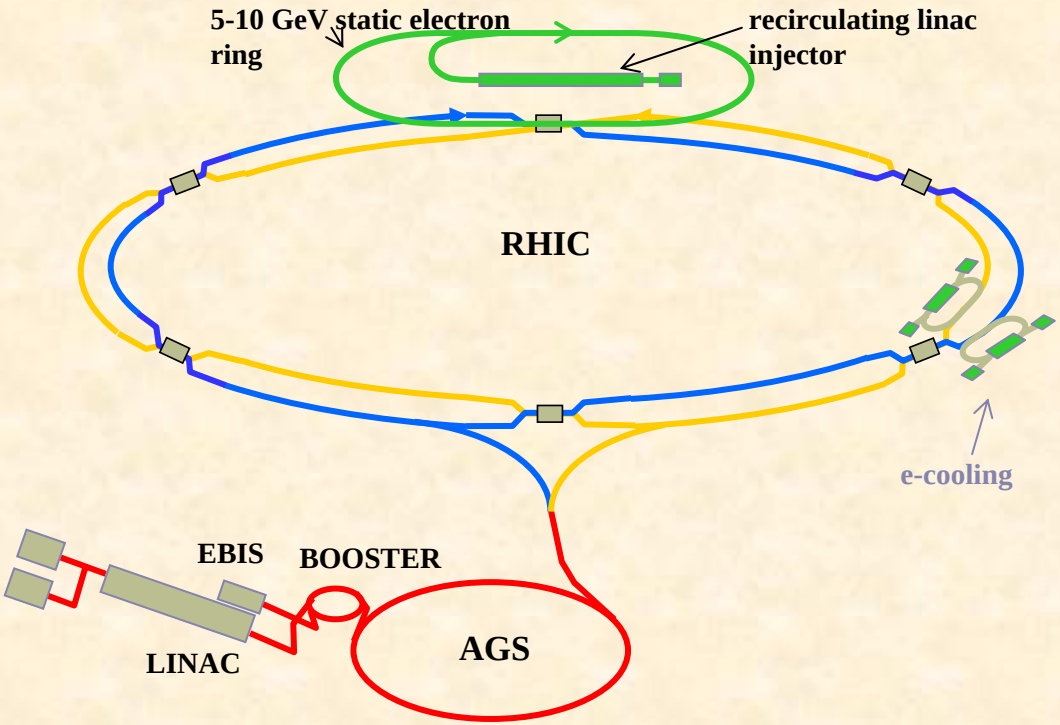
- According to the choice of the electron accelerator design two eRHIC design options under the consideration:
  - **Ring-ring**; On base of an electron storage ring
  - **Linac-ring**; On base of electron linear accelerator

- Two possible operation modes:
  - **Parallel mode**: p-p (or ion-ion collisions) in two RHIC interaction points (IP6 and IP8) in the same time with e-p (ion) collisions in the eRHIC IP.

    This was considered the main operation mode in the eRHIC ZDR design having effect on the design luminosities of eRHIC.

  - **Dedicated mode**: only e-p (ion) collisions.

Ring-ring design option



- The electron ring of 1/3 of the RHIC ion ring circumference at either 12 or 4 o'clock region.
- Full energy injection using polarized electron source and 10 GeV energy linac.
- Polarized positrons can be used too.
- Longitudinal polarization produced by local spin rotators in interaction regions.

Electron accelerator design led by Bates

Luminosity for ring-ring option

- Luminosity limitation comes from beam-beam effects and from interaction region magnet aperture:

$$L = f_c \frac{\pi \gamma_i \gamma_e}{r_i r_e} \xi_{xi} \xi_{ye} \sigma'_{xi} \sigma'_{ye} \frac{(1+K)^2}{K}$$

- Beam-beam limits (from world experience, RHIC operation experience and initial beam-beam simulation results):

  $\xi_e < 0.08$, $\xi_i < 0.02$ (total from all collision points)

- From interaction region design :

  $\sigma_i' \leq 95$ μrad and $K=1/2$ (σ_y/σ_x beam size ratio; elliptical beams)

- Matched electron and ion beam sizes at the IP

- $f_c = 28.15\ MHz$: 360 bunches in the ion ring, 120 bunches in the electron ring

Ring-ring option parameters for e-p collisions

	High energy setup		Low energy setup	
	p	e	p	e
Energy, Gev	250	10	50	5
Bunch intensity, 10^{11}	1	1	1	1
Ion normalized emittance, π mm.mrad, x/y	15/15		5/5	
rms emittance, nm, x/y	9.5/9.5	53/9.5	16.1/16.1	85/38
beta*, cm, x/y	108/27	19/27	186/46	35/20
beam-beam parameters, x/y	0.0065/0.0033	0.029/0.08	0.019/0.0095	0.036/0.04
$\kappa=\varepsilon_y/\varepsilon_x$	1	0.18	1	0.45
Luminosity, 1e32, $cm^{-2}s^{-1}$	4.4		1.5	

No cooling
2 p-p IPs assumed

Cooling needed
No p-p IPs allowed

Ring-ring option parameters for e-Au collisions

	High energy setup		Low energy setup	
	Au	e	Au	e
Energy, Gev/u	100	10	100	5
Bunch intensity, 10^{11}	0.01	1	0.0045	1
Ion normalized emittance, π mm, x/y	6/6		6/6	
rms emittance, nm, x/y	9.5/9.5	54/7.5	9.5/9.5	54/13.5
beta*, cm, x/y	108/27	19/34	108/27	19/19
beam-beam parameters, x/y	0.0065/0.0033	0.0224/0.08	0.0065/0.0033	0.02/0.04
$\kappa=\varepsilon_y/\varepsilon_x$	1	0.14	1	0.25
Luminosity, 1e30, $cm^{-2}s^{-1}$	4.4		2.0	

Electron cooling of Au beam is required to achieve and maintain listed Au emittance values

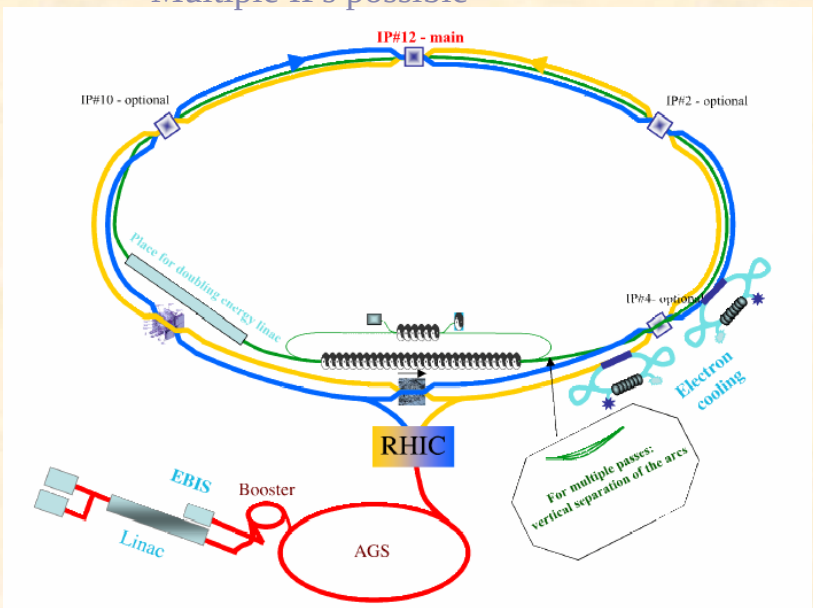
Ring-ring option parameters for e-^{3}He collisions

	High energy setup		Low energy setup	
	He	e	He	e
Energy, Gev/u	167	10	167	5
Bunch intensity, 10^{11}	0.7	1	0.18	1
Ion normalized emittance, π mm, x/y	10/10		10/10	
rms emittance, nm, x/y	9.4/9.4	48/13	9.4/9.4	48/13
beta*, cm, x/y	108/27	21/19	108/27	21/19
beam-beam parameters, x/y	0.0065/0.003	0.045/0.08	0.0065/0.003	0.02/0.04
$\kappa=\varepsilon_y/\varepsilon_x$	1	0.28	1	0.28
Luminosity, 1e32, $cm^{-2}s^{-1}$	3.1		0.8	

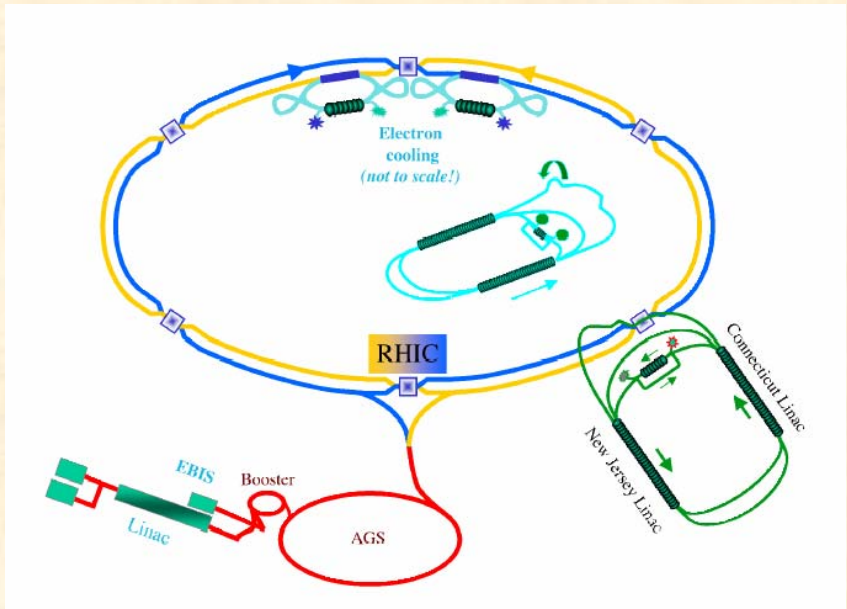
Linac-Ring Option

- Two possible designs are presented in the ZDR Appendix A (V. Litvinenko et al).
- Electron beam is transported to collision point(s) directly from superconducting energy recovery linac (ERL).
- 450mA electron current; 10 GeV energy.

Electron arcs in the RHIC tunnel.
Multiple IPs possible



Local accelerator with
e-p collisions in IP4



Linac-Ring Option

- Main features:
  - No beam-beam limitation for electron beam.
  - Less limits on interaction region design. Allows round beam collision geometry.
  - Much simpler electron polarization handling.
  - No positrons from the ERL.

Requires R&D studies for:

- High current polarized electron source *(M.Farkhondeh's talk)*
- Energy recovery technology for high energy and high current beams *(I.Ben-Zvi's talk)*

Linac-Ring parameters

RHIC	main case	*option*
Ring circumference [m]	3834	
Number of bunches	360	
Beam rep-rate [MHz]	28.15	
Protons: number of bunches	360	*120*
Beam energy [GeV]	26 - 250	
Protons per bunch (max)	$2.0 \cdot 10^{11}$	$6 \cdot 10^{11}$
Normalized 96% emittance [μm]	14.5	
β^* [m]	0.26	
RMS Bunch length [m]	0.2	
Beam-beam tune shift in eRHIC	0.005	
Synchrotron tune, Qs	0.0028 (see [2.4])	
Gold ions: number of bunches	360	*120*
Beam energy [GeV/u]	50 - 100	
Ions per bunch (max)	$2.0 \cdot 10^{9}$	$6 \cdot 10^{9}$
Normalized 96% emittance [μm]	6	
β^* [m]	0.25	
RMS Bunch length [m]	0.2	
Beam-beam tune shift	0.005	
Synchrotron tune, Qs	0.0026	
Electrons:		
Beam rep-rate [MHz]	28.15	*9.38*
Beam energy [GeV]	2 - 10	
RMS normalized emittance [μm]	5- 50 *for $N_e = 10^{10} / 10^{11}$ e^- per bunch*	
β^*	~ 1m, *to fit beam-size of hadron beam*	
RMS Bunch length [m]	0.01	
Electrons per bunch	$0.1 - 1.0 \cdot 10^{11}$	
Charge per bunch [nC]	1.6 – 16	
Average e-beam current [A]	0.045 – 0.45	*0.015 – 0.15*

Luminosity is defined by hadron beam

$$L = \gamma_i \, f_c \, N_i \, \frac{\xi_i \, Z_i}{\beta_i^* \, r_i}$$

	Luminosity, 1e33, $cm^{-2}s^{-1}$
p 50 Gev	0.55
p 250 Gev	2.74
Au 100 Gev/u	0.03
Dedicated p 250 Gev	9.4

Summary

- Two design options for eRHIC are under development: ring-ring and linac-ring.
- At similar level of electron beam intensities the linac-ring design provides higher luminosity.
- Ring-ring option luminosity is limited by beam-beam effects and IR design.
- Linac-ring luminosity is defined by hadron beam. So better understanding of hadron beam limits (especially limits on bunch intensities) will help to understand the maximum achievable luminosity.